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QUARTERLY PROGRESS REPORT NUMBER 3, 1 JULY-30 SEPTEMBER 1968.(U)
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DEFENSE RESEARCH LABORATORY

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5 November 1968

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QUARTERLY PROGRESS REPORT No. 3 UNDER CONTRACT N00024-68-C-1149 (U)

1 July - 30 September 1968

NAVAL SHIP SYSTEMS COMMAND
Contract N00024-68-C-1149
Project Serial No. SF 1010316, Task 08515

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~~UNDER CONTRACT N00024-68-C-1149 (U)~~

1 July — 30 September 1968 .

12 24p.

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Project Serial No. SF 1010316, Task 08515

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A. AN/SQS-23 Digital FM Classifier
(K. W. Harvel, W. D. Howard, and F. L. Weisser)

(U-~~FOUO~~) The two weeks of submarine target data collection were completed near the end of the current reporting period. The FM equipment was transported to San Diego and installed aboard USS ROGERS (DD 876) with a minimum of difficulty. We were particularly pleased to be able to use spare sonar and fire control cables for all of the signal connections required, thereby avoiding the task of stringing cable through the ship. Main power for the FM equipment was tapped from the fire control switchboard.

(U-~~FOUO~~) Defense Research Laboratory (DRL) personnel assisted in calibrating the receiving portion of the sonar system. Repeating the installation checkout required many calibration adjustments, the most troublesome of which was the correction of tape path alignment errors on the PME.

MICRO BAR

(U-~~FOUO~~) Standard acoustic measurements were made on the system transmitter and receiver. Audio scanner receive sensitivity of -17 dB re 1 μbar was measured, with side lobe suppression a relatively poor 13 dB. The receive bandwidth was modified for the testing project; the measured response is shown on Fig. 1. A few individual stave measurements were performed with the results shown on Figs. 2 and 3. Figure 2 shows the receiving response of stave 1, and Fig. 3 shows a comparison of the acoustic signal response of several transducer staves. The staves were connected to the preamplifiers during these measurements.

(U-~~FOUO~~) Source level was observed to vary depending on the transmitter combination used. With either the "A" or "B" transmit section the

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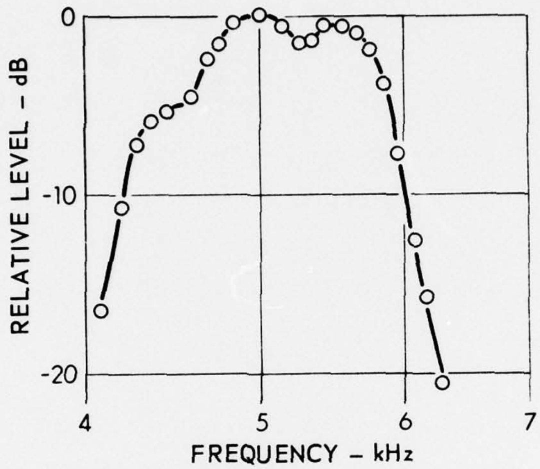
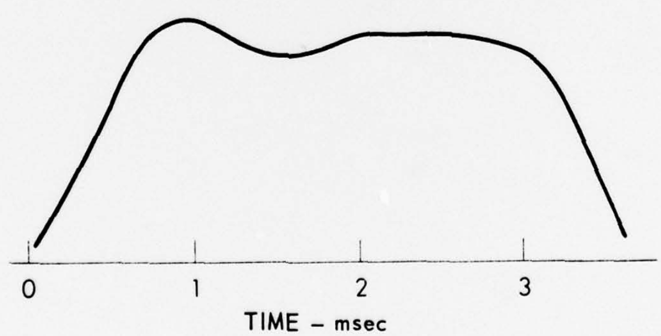


FREQUENCY RESPONSE



TIME RESPONSE

FIGURE 1
AUDIO BEAM FREQUENCY AND PULSE RESPONSE
USS ROGERS (DD 876)
AUGUST 1968

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AS-68-1469
KWH - RFO
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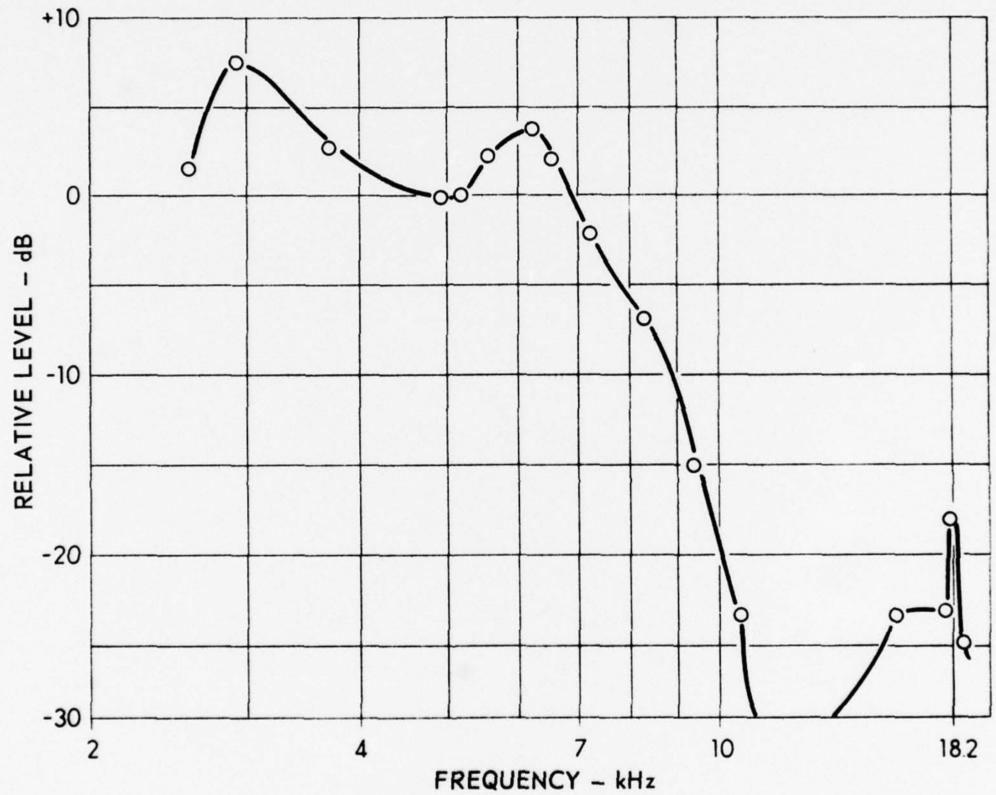

FIGURE 2
STAVE 1 VOLTAGE RECEIVING RESPONSE
TEST DISTANCE: 16 yd
USS ROGERS (DD 876) AUGUST 1968

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KWH - RFO
11 - 6 - 68

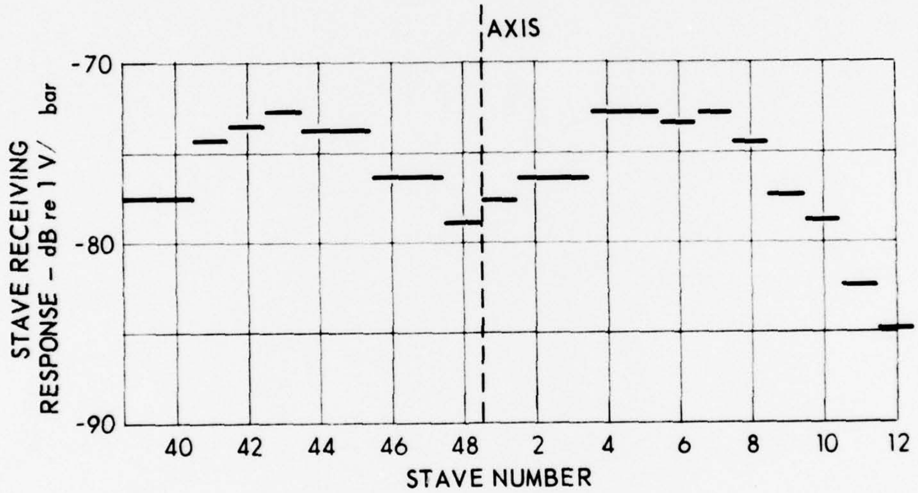

FIGURE 3
STAVE AMPLITUDE RESPONSE
TO TEST PROJECTOR AT BOW
USS ROGERS (DD 876) AUGUST 1968

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AS-68-1471
KWH - RFO
11 - 7 - 68

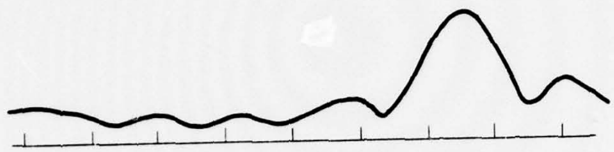
source level was measured to be 136 dB, while with "A and B" transmitters used, the source level decreased by 2 1/2 dB. "A and B" mode was used for the data recording. It was realized that the transmission system needed to be recalibrated, but by the time the deficiency was noted the task could not be accomplished before scheduled sailing time, and the loss of source level was estimated to be of insufficient importance to limit our data collection.

(C) Using the 136 dB source level the beam patterns and sound field of the first four harmonic frequency components were measured. No effort was made to reposition the hydrophone at the higher frequencies, so the levels reported may be less than the maximum value. Figure 4 shows the RDT envelopes at the fundamental, 5 kHz, and the second harmonic, 10 kHz. The 15 kHz component showed no major lobe structure, while the major lobe returned at 20 kHz. The levels are summarized in the table below:

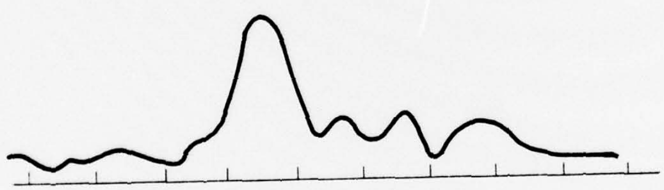
Frequency Component	Amplitude re 1 μbar	Measured 6 dB Pulse Length
5 kHz	136 dB	25.3 msec
10 kHz	118 dB	16.7 msec
15 kHz	98 dB	---
20 kHz	108 dB	10 msec (3 lobes)

At 20 kHz there are three lobes of near-equal amplitude, two lobes being displaced 28 deg either side of the main lobe, approximately corresponding to the expected main lobe ambiguity from elements spaced two wavelengths apart.

(C) The purpose of the current data collection period is to obtain the recordings necessary to compare the classification performance of several systems. ASPECT, sonar, FM and "FM-PAIR" data were emphasized. Thirty-four of the very useful Alpha/Sierra data



5 kHz – SOURCE LEVEL – 136 dB



10 kHz – SOURCE LEVEL – 118 dB

FIGURE 4
RDT TRANSMISSION COMPONENTS (U)
USS ROGERS (DD 876) AUGUST 1968
SCALE: 20 msec/div

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AS-68-1472
KWH - RFO
11-7-68

sequences and ninety of the Bravo/Sierra runs were completed. This is almost twice the estimated minimum amount of submarine data required to perform an operator classification comparison. Nonsubmarine records were obtained for six Alpha/November sequences and seven Bravo/November sequences--about 15% of the estimated minimum nonsubmarine data. "Chatterbox" echoes recorded at the request of Bendix Corporation were obtained for twelve submarine and three nonsubmarine sequences.

(C) Data collection will resume in early October for the recording of nonsubmarine segments. An additional requirement was added for this second recording period: sufficient data were needed to compare operator detection performance with broadband vs narrowband reverberation background. Alerted and nonalerted minimum detectable signal levels will be measured at the AN/SQS-23 playback facility. An FM vs cw pulse audio experiment, which was reported previously, indicated a performance improvement of 8 dB for fully alerted detection in broadband vs narrowband interference, respectively. The test was not sufficiently realistic to anticipate that the same gain can be realized in practice, and the current data should allow a much better measure of relative operator performance.

(C) Design of the circuit components necessary to perform an experimental FM modification to the AN/SQS-23 has continued. The original transmit oscillator was composed of three crystal oscillators operating at 18, 20, and 22 kHz, two discrete component flip-flops, which divide the oscillator frequency to 4.5, 5, and 5.5 kHz, a transmit enabling gate, a low-pass filter, and a transformer coupled output stage. The redesigned oscillator retained all the functions of the original oscillator and, in addition, three selectable FM oscillators with center frequencies of 4.5, 5, and 5.5 kHz on an original size printed circuit board. Operator selectable FM or cw mode is accomplished by the addition of a momentary switch on

the sonar control indicator, while the selection of a particular frequency, whether cw or FM, uses the existing frequency deviation switch (no rewiring is necessary).

(C) To retain all the functions of the original oscillator board, and still have the board space necessary for the addition of the FM capability, two TTL integrated circuits in the 14 pin dual-in-line configuration replaced the discrete flip-flops and the transmit enabling gate. The crystal oscillators, the filter, and the output stage were retained. The FM oscillator is a unijunction transistor relaxation oscillator whose capacitor charging rate is varied by the ramp generator and the transmit frequency deviation switch.

(C) The FM oscillator and the ramp generator are very similar circuits. The capacitor charging rate of the ramp generator is held constant by a constant current source, resulting in a linear ramp. The time constant of this RC oscillator is chosen to obtain a period of 50 msec. The ramp generator is free running and is not synchronized to the enabling gate on-time. The FM oscillator capacitor charging rate is changed by the linear ramp, resulting in a linear FM slide that varies 160 Hz either side of the selectable center frequency.

(C) The decision to use a rather simple unijunction FM oscillator instead of a more precise voltage controlled oscillator was based primarily on the amount of board space available. A single unijunction oscillator is capable of producing all three center frequencies required with a minimum of space consuming circuitry. The major disadvantage of such a circuit is the difficulty of achieving frequency stability with varying temperature. In order to obtain an acceptable variation of less than 20 (±10) Hz along any portion of the FM slide, it has been necessary to temperature cycle each board to select the proper temperature compensating resistor.

(C) It should be pointed out that an attempt was made to achieve crystal controlled FM slide center frequencies by mixing, but although two different mixing circuits were designed, the entire slide frequency was still dependent upon the stability of the least stable (FM) oscillator.

B. <u>Systems Analysis</u>
<u>(S. P. Pitt)</u>

(U-~~FOUO~~) Work continued in all areas mentioned in the previous progress report. However, only studies where specific information was generated will be mentioned here.

1. <u>Floating Point Correlator</u>

(C) The data necessary to complete this study were reprocessed during this quarter after it was discovered that the quantization routine in the quadrature correlation version of the program was not precisely correct. The differences lay in the lower order (least significant) bits. Comparison of these data after reprocessing showed only slight differences in nearly all cases. The correlator study is now essentially complete and will be described in a technical memorandum shortly. Recently, however, the question of how useful this type of quantization is for beamforming has been raised. The possibility of quadrature beamforming digitally using floating point quantization has been discussed and partially analyzed; the result is as follows. Using four bits (exponential) quantization, a dynamic range of $20 \log 2^{15} = 90$ dB can be achieved. Using quadrature sampling, beamforming can be done at low frequencies in times that would apparently allow digital formation of many beams in the time between samples for each beam, for typical sonar bandwidths, allowing electronic beam scanning. Whether the errors involved will allow accurate enough beamforming remains to be seen; a preliminary

to $2/W$, where W is the bandwidth of the impinging signal, $X(t - \tau) \doteq X(t)$, $Y(t - \tau) \doteq Y(t)$, so that the transformation becomes a simple rotation.

(C) A beam formed by this type combination of several receivers would have the same characteristics as the present beams formed in the AN/SQS-23C preformed beam receiver, except for the errors due to quantizing. A short study to determine the efficiency of this type of beamforming has been started: the complicated quantizing schemes already being used in the correlator study should allow rapid simulation and testing of the techniques. A technical memorandum is anticipated upon completion of the study.

2. Covariance Analysis

(C) The program to produce covariance analyses for input signal ensembles has been completed and used extensively in analysis of ASPECT data. The beam data for the submarine reported previously were so analyzed and plotted on a graph with abscissa, the time between members of the ensemble, and ordinate, the normalized cross-correlation coefficient, as shown in Fig. 5. The periodic nature of these data is quite obvious. This analysis led to the digitizing and analysis of echoes from other aspect angles. The analysis is nowhere near complete, but preliminary results indicate that the same periodicity exists for stern aspect data. The most reasonable explanation for the periodicity is the oscillation of the submarine about its desired course. Naval Ship Research Development Center was contacted to obtain data which would support this as a possibility; expected amplitude of such oscillations and data have been promised. In order to demonstrate that this is the true explanation, it is planned that data will be analyzed for many different conditions on the same target, i.e., depth, speed, and aspect angle. By correlating the results with expected results using the "oscillation" hypothesis, its validity (hopefully) can be determined.

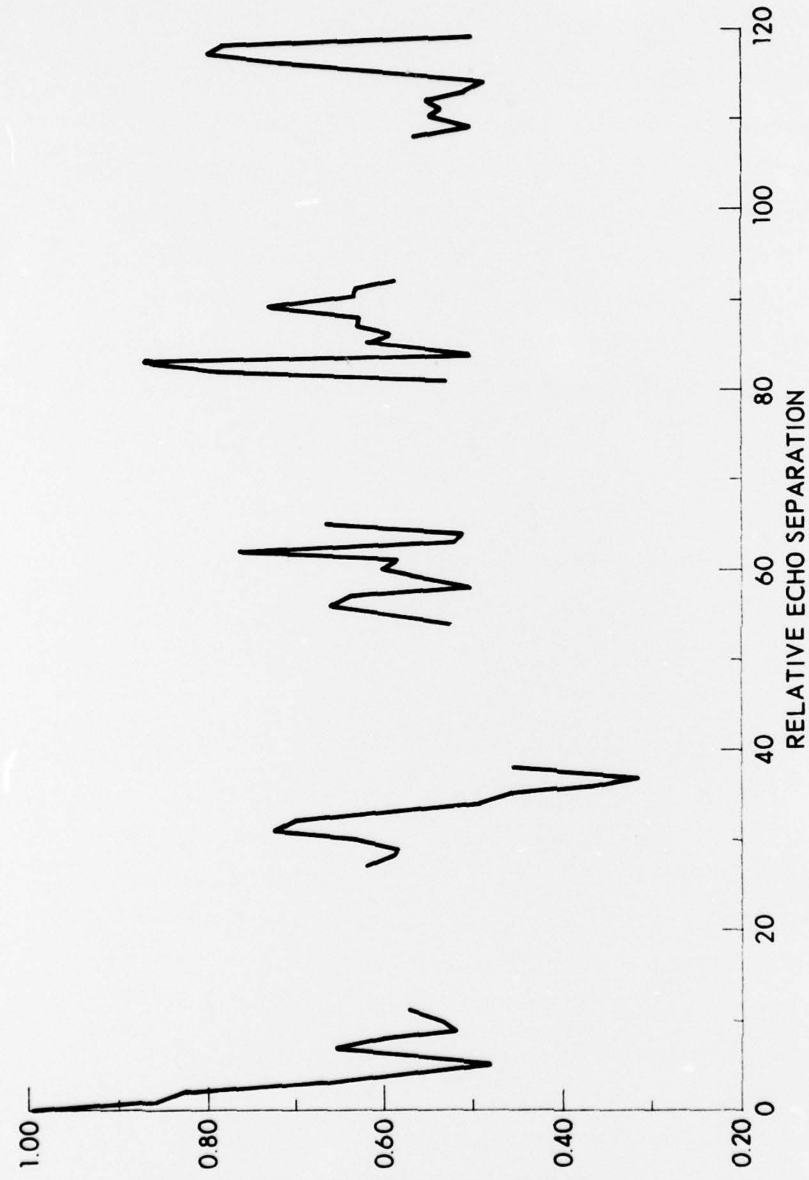

FIGURE 5
PERIODIC NATURE OF
SEQUENCE OF ASPECT ECHOES (U)
BEAM SUBMARINE

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3. Multipath

(U-~~FOUO~~) The problem of estimating and eliminating the effects of multipath from sonar echoes has been pursued following examination of these data, described in the previous progress report. An analytical treatment of the problem follows:

Consider a signal

$$X(t) = f(t) + a\, f(t - T) \quad , \tag{1}$$

where

$f(t)$ is the signal to be expected in the absense of multipath, and
T is the delay of the second path.

Let $a \neq 1$; for convenience, $a < 1$. There are several ways to represent the recovery of $f(t)$ from $X(t)$, T and a being known or estimated.

(U-~~FOUO~~) *In the frequency domain,*

$$\hat{X}(f) = \hat{f}(f)\left\{1 + a\, e^{-2\pi i f T}\right\} \quad , \tag{2}$$

from which

$$\hat{f}(f) = \frac{\hat{X}(f)}{1 + a\, e^{-2\pi i f T}} \quad , \tag{3}$$

with $f(t)$ being recovered according to

$$f(t) = \int_{-\infty}^{\infty} \hat{f}(f)\, e^{2\pi i f t}\, df \quad .$$

(U-~~FOUO~~) Now, in the complex frequency plane we can determine values of f such that

$$1 + a\, e^{-2\pi i f T} = 0 \quad ,$$

or

$$\ell n(a\, e^{-2\pi i f T}) = \ell n(-1) = \ell n(e^{\pm i\pi}) \quad ,$$

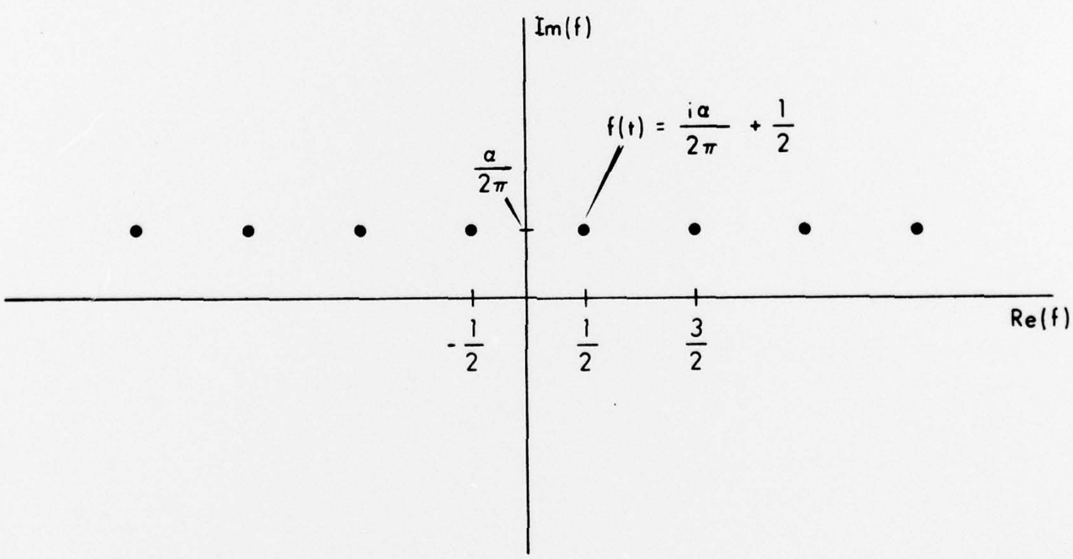
$$\ell n\, a - 2\pi i f T = \pm i\pi,\ 3i\pi,\ \ldots$$

$$fT = \frac{-i\ell n\, a}{2\pi} \pm \left(\frac{1}{2}, \frac{3}{2}, \ldots\right) \quad ,$$

$$= \frac{i\alpha}{2\pi} \pm \left(\frac{1}{2}, \frac{3}{2}, \ldots\right) \quad ,$$

where

$$a = e^{-\alpha} < 1,\ \alpha > 0 \quad .$$



(U-~~FOUO~~) With $\hat{X}(f)\, e^{2\pi ift}$ being analytic in the upper half-plane, we might close the contour above and evaluate the residues of

$$\frac{\hat{X}(f)\, e^{2\pi ift}}{1 + a\, e^{-2\pi ifT}} ,$$

at the zeros, summing then to get f(t).

(U-~~FOUO~~) However, there are far more convenient inversions. Since $a < 0$, we expand Eq. (3) for real f:

$$\hat{F}(f) = \hat{X}(f)\left\{1 - a\, e^{-2\pi ifT} + a^2\, e^{-2\pi if2T} - a^3\, e^{-2\pi if3T} \ldots\right\} , \quad (5)$$

and invert to get

$$\begin{aligned} f(t) &= X(t) - aX(t - T) + a^2X(t - 2T) - a^3X(t - 3T) \ldots \\ &= X(t) + \sum_1^\infty (-a)^n\, X(t - nT) \quad . \end{aligned} \quad (6)$$

This agrees with intuitive notions for recovery of f(t) from X(t).

(U-~~FOUO~~) Equation (6) may be obtained also by using an operator notation, introducing a time-translation operator $S(t) = e^{T\partial/\partial t}$,

$$f(t - T) = S(-T)f(t) \quad . \quad (7)$$

Then

$$X(t) = [1 + aS(-T)]f(t) \quad , \quad (8)$$

$$f(t) = [1 + aS(-T)]^{-1}\, X(t) \quad ; \quad (9)$$

The operator maybe expanded:

$$
\begin{aligned}
[1 + aS(-T)]^{-1} &= 1 - aS(-T) + aS(-T) \times aS(-T) + \ldots \\
&= 1 - aS(-T) + a^2S(-2T) - a^3S(-3T) + \ldots \quad .
\end{aligned}
\tag{10}
$$

or,

$$
f(t) = X(t) + \left[\sum_{1}^{\infty} (-a)^n \, S(-nT) \right] X(t) \quad , \tag{11}
$$

which is equivalent to Eq. (6).

(U-~~FOUO~~) A simpler implementation of the elimination process can be obtained for signals of finite length by assuming that epoch (t_o) can be determined and that the leading edge (T sec) of the signal X(t) is purely f(t). Then

$$
f(t_o + t - T) = \frac{X(t_o + t) - f(t_o + t)}{a} = 0 \quad , \quad 0 \leqq t < T \ , \tag{12}
$$

so that

$$
f(t_o + t) = X(t_o + t) - af(t_o + t - T) \quad , \quad T \leqq t < 2T \ . \tag{13}
$$

The same process is repeated for $2T \leqq t < 3T$, using the reconstructed $f(t_o + t)$ in the last term. Hence, by storing the entire signal, one can obtain the delayed version of the signal by a simple subtraction process. The problem remaining is, of course, that a and T must be known or estimated.

(U-~~FOUO~~) A computer program to implement Eq. (13) was generated during this quarter. The values of a and T were estimated in two ways,

(1) by visual inspection, and (2) by use of the autocorrelation function for $X(t)$. It is obvious by inspection that, given $X(t)$ as in Eq. (1), the autocorrelation function $\phi(\tau) \equiv E[X(t)\,X(t - \tau)]$ will contain relative peaks at (at least) $\tau = 0$ and $\tau = T$. A computer program was written to compute $\phi(\tau)$ and, from $\phi(\tau)$, estimate a and T. The program has been tested on analytically generated data and real data. The results of the study will be reported in the next quarter.

4. Digitized Sonar Stave Data

(U-~~FOUO~~) During this quarter Professor E. A. Patrick and Mr. L. Shen visited DRL for a cooperative program between DRL and Purdue University. Both DRL and Purdue initiated programs to examine sonar data extracted by both space and time sampling of the acoustic field. At present, DRL's effort is directed primarily to an examination of the reverberation and noise fields and beamforming, whereas Purdue is studying the representation of echoes for recognition purposes. For both groups, sampled data from the output of individual staves of the AN/SQS-23 sonar system were required. The programming necessary to obtain such samples was generated at DRL and these data were obtained as follows. The Ampex FR-1800 was used to record the outputs of the ten staves in the direction of the target during playback of sonar tapes on the SME. These data were recorded at 60 ips along with the reference track from the SME tapes and the output of the audio beamformer. By careful manipulation, all ten channels were digitized in quadrature for most of these data recorded, which consisted of submarine echoes at various aspect angles. Copies of these data were forwarded to Purdue University. Time has not permitted a significant amount of analysis by either group. Nonsubmarine data must eventually be obtained in the same manner for further development.

(U-~~FOUO~~) One interesting observation was made during handling of these data; by comparing the signal-to-noise ratio (S/N) on individual staves with that from the audio beamformer, it was found that, at least for one case, the gain achieved by the beamformer was about 12 to 13 dB. The theoretical gain, assuming independent Gaussian noise at the staves, is about 16 dB. The difference could be caused by dependence of the noise samples, by incoherence of the echo from stave to stave, by inaccurate beamforming, or by all three. All of the possible causes are being examined.

5. Clipped Correlator

(U-~~FOUO~~) The analysis of the inconsistent output of the clipped correlator, discussed in the previous progress report, was postponed because of lack of availability of the A/D and because of the sea trip. It is expected that the study will be completed during the next quarter.

6. Comparison Between Direct Quadrature Correlation and Quadrature Correlation Using FFT

(U-~~FOUO~~) Experiments with real data were run during this quarter to compare correlations using the direct method with those using FFT. A program that computes the Fast Quadrature Transform was developed and used by the Computer Science Division to generate envelopes of correlation functions from quadrature sampled data. The machine language, direct quadrature correlator program of Systems Analysis was used on these same data. The outputs are compared in Fig. 6, where it is seen that they are identical. For this case, where a maximum of 512 data points were used, the direct method was faster. It is expected that for more points the FQFT method could probably be streamlined (using machine language) to make it somewhat faster,

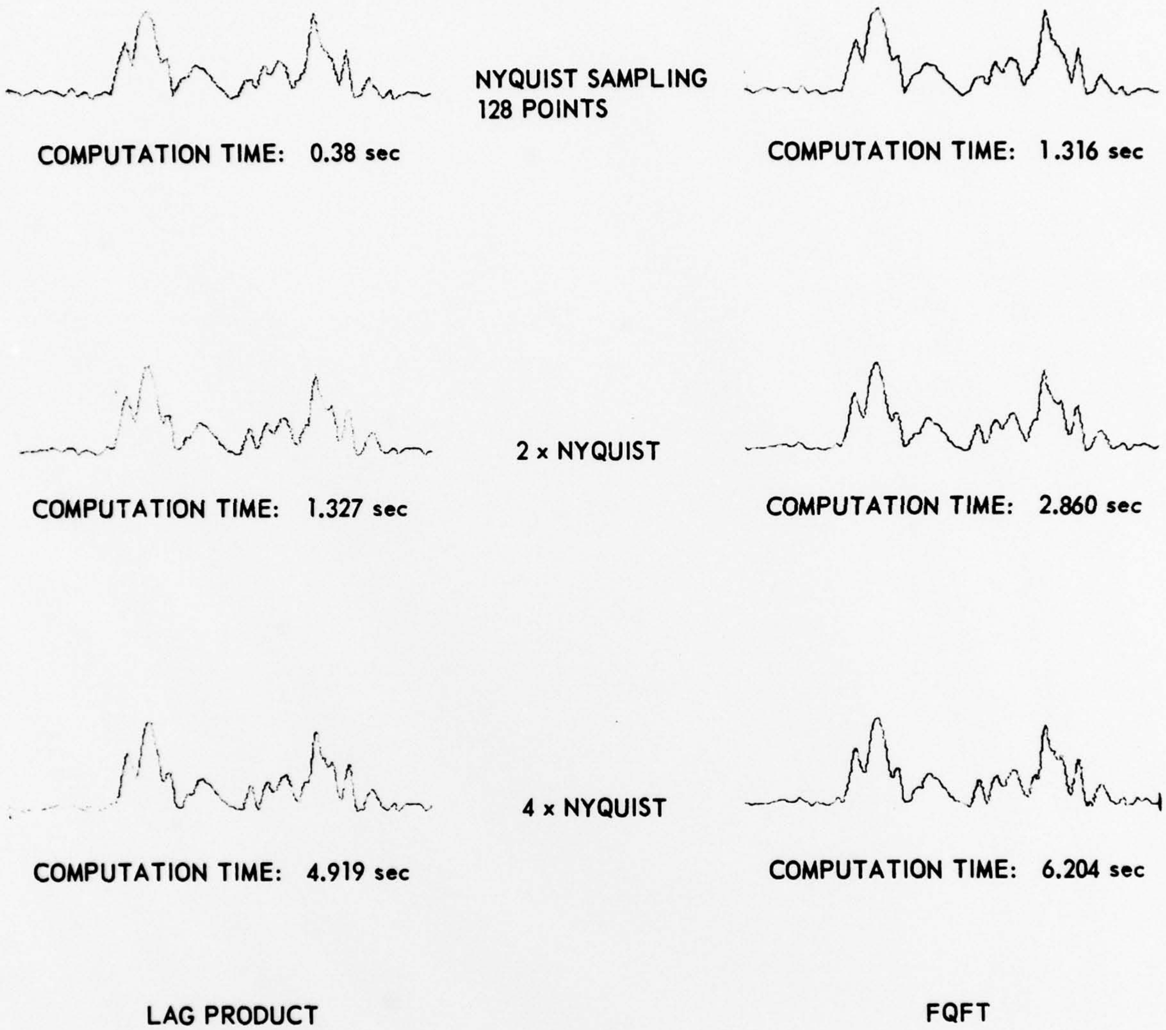


FIGURE 6
COMPARISON OF CROSSCORRELATION ENVELOPES
USING LAG-PRODUCT AND FAST
QUADRATURE FOURIER TRANSFORM (FQFT) METHODS
BOW ASPECT SUBMARINE ECHO

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whereas the direct method has been optimized in speed as much as possible on the CDC 3200.

(U-~~FOUO~~) The paper on quadrature sampling will, according to the present schedule, appear in the correspondence section of the November issue of The Journal of the Acoustical Society of America, instead of the October issue, as reported earlier.

5 November 1968

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